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Nutritive Quality of Four Perennial Grasses as Affected by Species, Cultivar, Maturity, and Plant Tissue

J. F. Karn,* J. D. Berdahl, and A. B. Frank

ABSTRACT

Improved perennial grasses provide ranchers with high-quality forage for grazing and hay. However, in the Northern Great Plains of the USA, nutritive quality information is limited on both established and new cultivars. This study compares the nutritive quality of established and more recently released cultivars of crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schultes] (CWG), intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth and Dewey] (IWG), western wheatgrass [*Pascopyrum smithii* (Rydb.) Love] (WWG), and smooth bromegrass (*Bromus inermis* Leyss.) (SBG); evaluates the effect of plant maturity on tissue quality; compares nutritive quality differences among species; and evaluates nutritive quality relationships. Smooth bromegrass leaf tissue had the highest ($P < 0.05$) in vitro dry matter digestibility (IVDMD) and lowest neutral detergent fiber (NDF), but IWG and WWG had higher stem IVDMD. Few quality differences were detected between cultivars within a species, but 'Rosana' WWG had higher ($P < 0.10$) stem and whole plant IVDMD than the more recently released 'Rodan'. Leaf percentage differed significantly ($P < 0.05$) among species, with WWG (49.8%) having the highest, and CWG (21.2%) the lowest. Correlation coefficients between quality measurements suggest that if grass leaf tissue were selected for higher IVDMD, leaves should also have higher crude protein (CP) and lower NDF. This relationship was best illustrated with WWG for all three tissue types. The apparent lower quality of Rodan WWG compared with the older cultivar, Rosana, should caution plant breeders to monitor forage quality to ensure that selection for improved agronomic traits does not compromise nutritive quality.

In the Northern Great Plains region of the USA there is need for perennial grasses that furnish high-quality forage for beef cattle (*Bos taurus*) during all phases of the summer grazing season. However, most forage grasses used in this region have been developed and released based on characteristics related to their establishment and production rather than their nutritive quality. Well-established cultivars such as Nordan (Hein, 1955a) CWG, Lincoln (Hein, 1955b) SBG, and Oahe (Ross, 1963) and Greenleaf (Wilson and Smoliak, 1978) IWG were released partially because of good seedling vigor and ease of seedling establishment. Oahe IWG, Lincoln SBG, and 'Hycrest' (Asay, 1985) CWG, a hybrid of [*Agropyron cristatum* (L.) Gaertn.] and [*A. desertorum* (Fisch. ex Link) Schultes], were all released primarily because of high forage and seed yields. Greenleaf and Slate (Newell, 1974) IWG cultivars were released in part because they demonstrated good winter hardiness. Only in more recent times has forage quality and animal performance been considered as selection criteria in development of perennial grasses. 'Manska' (Berdahl et al., 1993) IWG was released primarily because of superior animal weight gains. Criteria for release of Badger (Casler and Drolsom, 1992) and Alpha (Casler and Drolsom, 1995) SBG cultivars included improved dry matter digestibility, and one of the positive traits of 'Douglas' (Asay et al., 1995), a hexaploid CWG, was its slow decline in quality with maturity, relative to diploid and tetraploid cultivars.

It is well established that maturation of forage tissue has a detrimental effect on whole plant nutritive quality (Pritchard et al., 1963; Kilcher and Troelsen, 1973), although less is known about the effect of maturity on specific cultivars that are widely grown in the Northern Plains of the USA and Canada (Lawrence and Warder, 1979). Leaf and stem quality in two SBG cultivars differed, with one cultivar having more digestible leaves and the other more digestible stems (Buxton and Marten, 1989). Comparisons with SBG and four other grasses suggested that differences among species were related more to traits such as herbage mass and leaf/stem ratio than to leaf and stem quality (Baron et al., 2000). Little is known about the nutritive quality of grass cultivars developed and released for use in the Northern Plains, and there is even less comparative data between older and more recently released cultivars. Thus, the objectives of this research were to: compare the nutritive quality of established and more recently released cultivars of four commonly seeded grass species in the Northern Plains, evaluate the effect of plant maturity on quality of different plant tissues, compare the nutritive quality of different grass species, and evaluate nutritive quality relationships.

MATERIALS AND METHODS

In May 1993, an experimental nursery, which included two cultivars of four cool-season perennial grass species, was established on Parshall fine sandy loam soils (coarse-loamy, mixed superactive, frigid, pachic Haplustrolls) near Mandan, ND (46°48′ N, 100°55′ W). The nursery contained Nordan and Hycrest CWG, Rosana and Rodan WWG, Lincoln and 'Mandan 404' SBG, and 'Reliant' and Manska IWG (Table 1). Four replications of each cultivar were established in a randomized complete block design in 3- by 6-m plots seeded in rows with a 15-cm spacing. Two rows of 'Fairway' CWG were sown between each plot to control spread of rhizomatous species into adjacent plots. Replications were separated by a 2.4-m

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Abbreviations: CP, crude protein; CWG, crested wheatgrass; IVDMD, in vitro dry matter digestibility; IWG, intermediate wheatgrass; NDF, neutral detergent fiber; SBG, smooth bromegrass; WWG, western wheatgrass.

Table 1. Comparison of cultivars, their release date, reason for release, and reference citation.

Cultivar	Species	Year released	Improved trait	Reference
Nordan	CWG	1953	seedling vigor	Hein, 1955a
Hycrest	CWG	1984	forage production	Asay, 1985
Rosana	WWG	1972	seedling vigor	Alderson and Sharp, 1994
Rodan	WWG	1983	drought tolerance	Barker et al., 1984
Lincoln	SBG	1942	wide adaptation	Hein, 1955b
Mandan 404†	SBG	–	nutritive quality	Alderson and Sharp, 1994
Reliant	IWG	1991	forage and seed yields	Berdahl et al., 1992
Manska	IWG	1992	animal weight gains	Berdahl et al., 1993

† Unreleased experimental line.

alleyway seeded to Fairway CWG. Nitrogen fertilizer was applied as ammonium nitrate (NH_4NO_3, 34–0–0) to plots each year in October, at the rate of 56 kg N ha^{-1}.

Forage samples were clipped at a 5-cm stubble height for nutritive quality analyses from all plots at vegetative, heading, anthesis, and anthesis + 10-d stages of maturity in 1994 and 1995. Growing season temperature and precipitation data for 1994 and 1995 are shown in Table 2. Stage of maturity clipping dates differed among species and years because of differences in plant development rates. In 1994 vegetative samples were collected on 20 May for SBG, CWG and IWG and on 27 May for WWG; anthesis +10-d samples were collected on 1 July for SBG and CWG; and on 6 July for WWG and 11 July for IWG. In 1995 vegetative samples were collected on 17 May for SBG, CWG and IWG and on 24 May for WWG; anthesis +10-d samples were collected on 13 July for SBG and CWG and on 19 July for IWG and WWG.

Within years, forage samples were clipped from a different portion of the plot at each sampling date. In September 1994, all plots were clipped to a uniform height to minimize any possible plot affects the following year. After clipping, samples were rinsed in distilled water to remove any contaminating soil and dried at 55°C in a forced air oven. All samples were ground through a 1-mm screen before analysis. Samples at the heading, anthesis, and anthesis + 10-d stages were separated into leaf (including sheath), stem, and inflorescence tissue before being ground. Forage samples at the vegetative stage of maturity were not separated by tissue type because they consisted primarily of leaf tissue. Dry weights were measured on leaf, stem, and inflorescence tissue to calculate the percentage of these tissues and to enable calculating nutritive quality data on a whole plant basis.

Samples were analyzed for NDF according to the procedures of Goering and Van Soest (1970). Neutral detergent fiber concentration in forage samples and in the residue following a 48-h in vitro fermentation was determined with an

Table 2. Precipitation and mean monthly ambient air temperature between April and August for 1994, 1995 and the 30-yr average for Mandan.

	Precipitation			Temperature		
Month	1994	1995	L.T. avg.†	1994	1995	L.T. avg.†
	mm			°C		
April	29.2	29.5	43.4	6.3	3.6	5.7
May	18.5	173.0	57.2	15.4	11.3	12.6
June	71.6	65.5	75.2	18.5	18.8	18.1
July	48.8	152.4	59.9	19.6	20.7	21.5
August	5.3	43.4	49.3	19.7	22.0	20.3

† Long term (L.T.) avg. = 30-yr average.

ANKOM fiber analyzer (ANKOM Technology, Fairport, NY) (Vogel et al., 1999). In vitro dry matter digestibility (true digestibility) was determined on forage samples by measuring NDF on the residue following a 48-fermentation (Goering and Van Soest, 1970). Nitrogen was determined on leaf and stem samples using a Carlo Erba Model NA 1500 series 2 nitrogen/carbon/sulfur analyzer (CE Elantech, Lakewood, NJ 08701). Crude protein was calculated by multiplying N by 6.25. Lack of sample material precluded measuring N on inflorescence samples.

Data were analyzed using the SAS MIXED procedure (Littell et al., 1996), with species and cultivar within species considered fixed and replication, replication × species, and replication × cultivar within species considered random effects. Years and stage of maturity were treated as repeated measures. Repeated measures were analyzed using unstructured and compound symmetry. Least squares means for year were separated by an F test, and means for species, cultivar and stage of maturity were separated by the SAS PDIFF option. Correlation coefficients between nutritive quality components within leaf, stem and whole plant tissue were calculated using SAS PROC CORR. Coefficients were calculated on data that were pooled over year, species, cultivar, and stage of maturity as well as by species and by stage of maturity. Data for cultivar comparisons within a species were considered significant at $P < 0.10$, all other data were considered significant at $P < 0.05$.

RESULTS

F values and statistical probabilities for main effects and interactions for leaf, stem, and whole plant tissue nutritive quality are summarized in Table 3. There were stage of maturity × year, species × year, and stage of maturity × species interactions, which indicate some lack of consistency of species effects over stages of maturity and years.

F values and statistical probabilities for leaf, stem, and inflorescence percentages are summarized in Table 4. Most main effects were significant, but only maturity × year and species × year interactions were significant.

Species

Leaf Tissue

Averaged over years and maturity stages, SBG leaf tissue had the highest IVDMD and the lowest NDF (Table 5), but there were significant interactions involving species, maturity and year (Table 3, Fig. 1, 2). Interactions suggest that IVDMD and NDF differences among species were not entirely consistent across maturity and year effects. Leaf CP was highest for IWG, SBG, and WWG with only CWG (127 g kg^{-1}) having a significantly lower ($P < 0.05$) value (Table 5). There was, however, a year × species interaction showing that all species except CWG had higher CP levels in 1995 than 1994 (Fig. 2A).

Stem Tissue

Stem IVDMD was highest ($P < 0.05$) for IWG and WWG (Table 5). Western wheatgrass had the lowest NDF (667 g kg^{-1}) and the highest CP (86 g kg^{-1}). The species × stage of maturity interaction indicated that

Table 3. Leaf, stem, and whole plant tissue IVDMD, NDF, and CP *F* values and significance for main effects and interactions.

	Leaf			Stem			Whole plant	
Effect	IVDMD	NDF	CP	IVDMD	NDF	CP	IVDMD	NDF
Species (S)	13.4**	19.1**	8.3**	14.4**	16.0**	17.3**	33.2**	18.9**
Cultivar (species) (C)	1.5	1.8	1.4	4.6**	2.9*	2.1	4.8**	1.8
Maturity (M)	455.8**	430.8**	173.0**	318.1**	29.8**	327.6**	492.3**	25.2**
Year (Y)	28.2**	205.8**	2.4	197.1**	346.8**	5.7*	258.0**	488.3**
M × Y	41.6**	151.5**	1.9	2.6	2.5	0.9	11.2**	0.6
S × Y	9.3**	26.6**	10.2**	7.0**	4.2*	2.0	20.7**	11.5**
S × M	6.0**	9.1**	2.6*	6.8**	5.7*	17.6**	5.7**	5.8**
C(S) × Y	0.6	1.9	2.6	1.9	1.4	0.8	1.7	1.1
C(S) × M	1.2	1.4	0.5	1.9	1.4	1.4	2.2*	1.7
S × Y × M	3.1**	2.7**	3.4**	6.5**	1.6	7.1**	4.7**	0.7
C(S) × M × Y	0.6	1.0	0.8	1.4	1.4	1.2	1.1	1.1

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

WWG stem tissue declined more in CP between heading and anthesis than the other three species (Fig. 1B).

Whole Plant Tissue

Whole plant IVDMD was highest in WWG and lowest in CWG (Table 5). There was a significant species × year interaction demonstrating that IVDMD declined little between years for IWG compared to the other three species (Fig. 2C). Smooth bromegrass and WWG had the lowest NDF. A species × year interaction for whole plant NDF showed that NDF was always higher in 1995 plant tissue, but there was less difference between years for IWG (Fig. 2D), which accounts in large part for the whole plant IVDMD interaction.

Cultivars

Leaf Tissue

There were relatively few differences between cultivars within a species for any nutritive quality trait (Table 6). Nordan CWG leaf tissue had higher ($P < 0.10$) IVDMD than Hycrest CWG, but there were no other differences for IVDMD between cultivars within the other three species. Hycrest CWG and Manska IWG leaf tissue had significantly higher ($P < 0.10$) NDF concentrations than their comparison cultivars. Within a species, no cultivars differed in leaf CP concentrations.

Stem Tissue

Stem tissue IVDMD was higher ($P < 0.10$) in Rosana than Rodan WWG (Table 6). Stem NDF was higher for Manska IWG and Rodan WWG than their respective, comparison cultivars. Crude protein was higher in Nordan than Hycrest CWG and in Lincoln compared to Mandan 404 SBG.

Table 4. Tissue percentage *F* values and significance for main effects and interactions.

Effect	Leaf	Stem	Inflorescence
Species (S)	83.31**	52.64**	28.74**
Cultivar (species) (C)	3.88*	1.58	5.78**
Maturity (M)	45.73**	27.78**	8.61**
Year (Y)	134.87**	73.98**	1.53
M × Y	6.89**	1.34	4.51**
S × Y	67.69**	30.02**	7.80**
S × M	1.72	1.06	0.54
C(S) × Y	0.27	0.58	2.19
C(S) × M	0.92	0.95	0.83
S × Y × M	0.74	1.26	1.68
C(S) × M × Y	0.77	0.88	0.46

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Whole Plant Tissue

Whole plant IVDMD was higher ($P < 0.10$) in Lincoln SBG and Rosana WWG than in their comparison cultivars (Table 6). Whole plant NDF was lower in Reliant than Manska IWG.

Stage of Maturity

Leaf Tissue

Leaf tissue IVDMD and CP declined from 863 and 184 g kg^{-1}, respectively, at the vegetative stage to 697 and 120 g kg^{-1}, respectively, at the anthesis + 10-d stage of maturity (Table 7). There was a year × stage of maturity interaction indicting that the decline in IVDMD as maturity advanced was greater in 1995 than 1994 (Fig. 1C). Leaf NDF increased as maturity advanced from the vegetative to anthesis + 10-d stage, which is consistent with changes in IVDMD and CP. A year × stage of maturity interaction for leaf NDF shows that in 1995 NDF was lower than 1994 at the vegetative stage, but was higher than 1994 at the other three stages of maturity (Fig. 1D).

Stem Tissue

Stem tissue was only available for heading through anthesis + 10-d stages of maturity, but IVDMD and CP declined consistently among the three maturities as did IVDMD and CP in leaf tissue (Table 7). Although stem tissue NDF also differed significantly among maturity stages, the change was not consistent; NDF was lowest at anthesis + 10-d and highest at anthesis.

Whole Plant Tissue

Whole plant tissue IVDMD declined from heading to anthesis + 10-d, which is consistent with both leaf and stem tissue (Table 7). A year × stage of maturity interaction shows that IVDMD declined more at the anthesis + 10-d stage of maturity in 1995 than in 1994 (Fig. 1E). On the other hand, whole plant NDF was lowest at heading (650 g kg^{-1}) as would be expected, while it was highest at anthesis (671 g kg^{-1}). The rather small dif-

Table 5. Species differences in IVDMD, NDF, and CP for leaf, stem, and whole plant tissue for the years 1994 and 1995. Means are averaged over cultivar, stage of maturity, and years.†

	Leaf			Stem			Whole plant		
Species	IVDMD	NDF	CP	IVDMD	NDF	CP	IVDMD	NDF	CP
	g kg^{-1}	—g kg^{-1} DM‡—		g kg^{-1}	—g kg^{-1} DM—		g kg^{-1}	—g kg^{-1} DM—	
CWG	762c	608a	127b	609b	690a	58c	638c	673a	–
IWG	776b	613a	154a	626a	695a	68bc	671b	675a	–
SBG	798a	571b	158a	599b	696a	61c	671b	644b	–
WWG	772bc	608a	161a	635a	667b	86a	688a	650b	–
SE	4.2	4.4	5.4	4.2	3.4	2.9	3.6	3.6	–

† Means in the same column with different letters are significantly different ($P < 0.05$).
‡ DM, dry matter.

ference in NDF between heading and anthesis + 10-d indicates that maturity had less effect on NDF than would be expected considering the decline in IVDMD.

Tissue Percentages

Leaf Tissue

Leaf percentage differed ($P < 0.10$) between the two comparison cultivars of all four species (Table 8). Hycrest CWG, Reliant IWG, Lincoln SBG and Rosana WWG all had a higher percentage of leaf tissue than their comparison cultivars.

There also were differences in leaf percentage among species, with WWG having the highest ($P < 0.05$) and CWG the lowest percentage (Table 8). There was, however, a species × year interaction that indicated that leaf percentage differed little between years for CWG and IWG, while leaf percentages were much higher in 1994 than 1995 for SBG and WWG (Fig. 2E). A stage of maturity × year interaction for leaf tissue percentage also occurred, with no decline in leaf percentage from anthesis to anthesis + 10-d in 1994 and an obvious decline in 1995 (Fig. 1F).

Stem Tissue

Stem percentage differed only for WWG cultivars, with Rodan having a higher ($P < 0.10$) percentage than Rosana (Table 8). All four species had significantly different stem percentages, with CWG having the highest percentage and WWG having the lowest. As with leaf tissue percentage, there was a significant species × year interaction for stem percentage, with SBG and WWG having large differences between years, while CWG and IWG had small differences between years (Fig. 2F).

Inflorescence Tissue

Inflorescence tissue percentages were higher ($P < 0.10$) for Nordan CWG, Manska IWG, and Mandan 404 SBG than their comparison cultivars, while WWG cultivars were not different (Table 8). Smooth bromegrass and CWG had the highest average percentage of inflorescence tissue and WWG had the lowest percentage.

Nutritive Quality Component Relationships

Leaf Tissue

Over all species there was a relatively high negative relationship between leaf IVDMD and NDF ($r = -0.85$**) (Table 9). Across all species, correlation coefficients for leaf CP vs. IVDMD and leaf CP vs. NDF were lower than for IVDMD vs. NDF. When relationships were calculated for individual species, all four species had a high negative correlation coefficient between IVDMD and NDF in leaf tissue. The highest individual species leaf tissue correlation coefficient between IVDMD vs. CP was for IWG ($r = 0.85$**). The CP vs. NDF relationship in leaf tissue was greatest for CWG ($r = -0.80$**), and least for SBG ($r = -0.44$**).

Stem Tissue

Relationships between quality components over all species for stem tissue were all lower than leaf tissue coefficients, with the highest correlation for IVDMD vs. CP ($r = 0.63$**) (Table 9). Correlation coefficients for IVDMD vs. NDF and IVDMD vs. CP for stem tissue were highest for WWG and SBG, respectively. Correlation coefficients between NDF vs. CP were all low and nonsignificant, while similar coefficients for leaf tissue were all significant and much higher.

Whole Plant Tissue

The correlation coefficient for IVDMD vs. NDF was highest for WWG ($r = -0.82$**) and lowest for IWG ($r = -0.21$) (Table 9).

Stage of Maturity

Stage of maturity had a substantial effect on leaf tissue quality component relationships, with IVDMD and NDF most highly correlated at the anthesis + 10-d stage of maturity ($r = -0.81$**) (Table 9). There appeared to be no relationship between leaf tissue CP and IVDMD at the vegetative stage of maturity in contrast to a correlation coefficient of $r = 0.71$** calculated over all species and stages of maturity. Leaf tissue CP and NDF had low correlation coefficients at all stages of maturity. Correlation coefficients between IVDMD vs. NDF for stem and whole plant tissue were relatively high at all three reproductive stages of maturity.

DISCUSSION

Species

Leaf tissue of all four grass species averaged over years and stage of maturity was adequate in CP (>120 g kg^{-1}) to meet most yearling steer and lactating

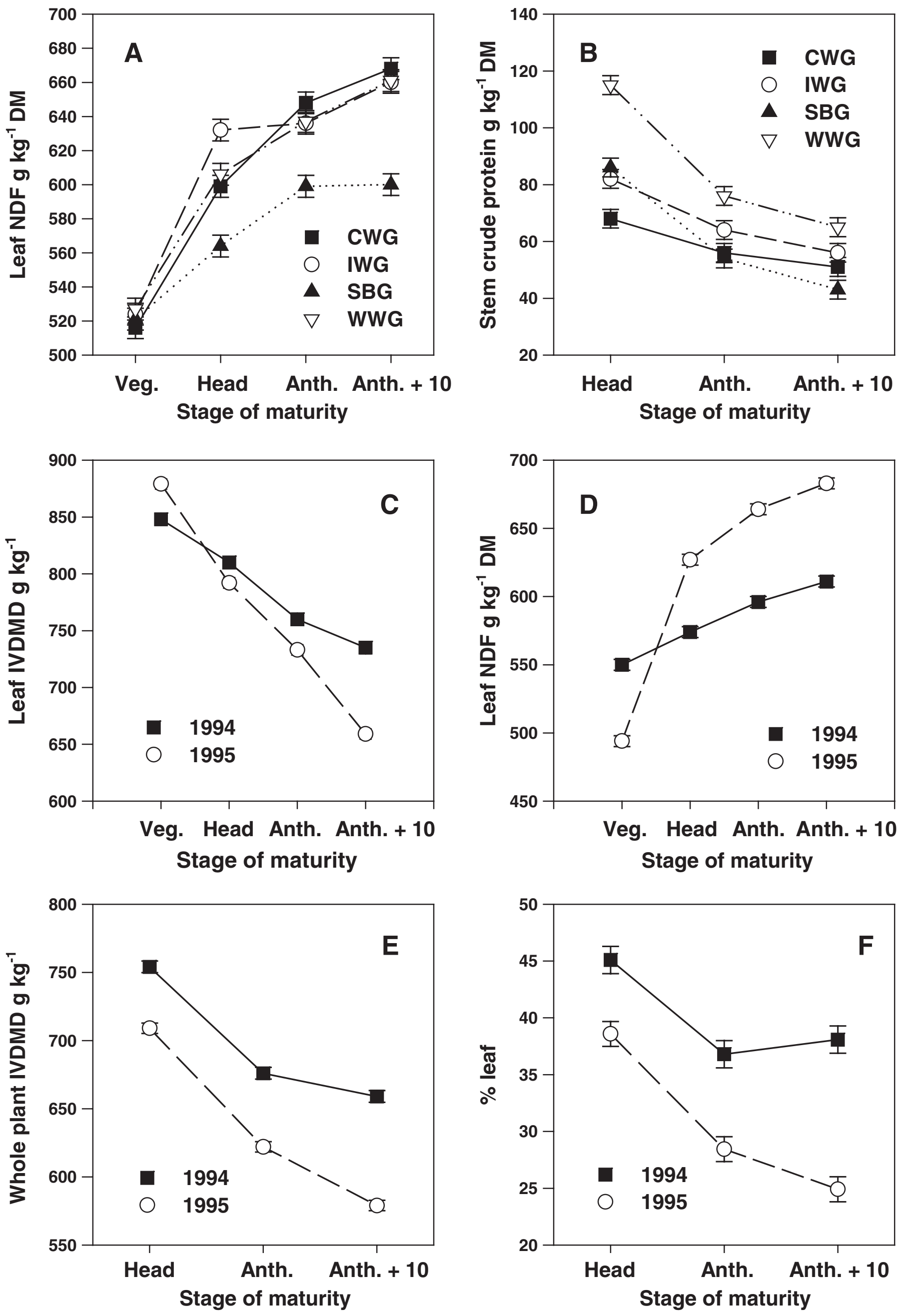

Fig. 1. Interaction effects of (A) species and stage of maturity for leaf NDF, (B) species and stage of maturity for stem CP, (C) stage of maturity and year for leaf IVDMD, (D) stage of maturity and year for leaf NDF, (E) stage of maturity and year for whole plant IVDMD, and (F) stage of maturity and year for whole plant leaf percentage. Standard error bars on C, D, and E are partially covered by graph symbols.

beef cow requirements (Table 5; NRC, 1996). However, stem tissue for all grass species, except for WWG, was deficient in CP for both beef cows and steers. A CWG diet containing 50% leaves and 50% stems would have been marginal in CP for moderately milking beef cows, while a similar WWG diet would have contained adequate CP for most growing yearling steers and moderately milking beef cows (NRC, 1996).

Smooth bromegrass leaves in the current study appear to have the highest quality in terms of IVDMD and CP, but WWG had significantly higher whole plant IVDMD. A species × stage of maturity interaction for leaf NDF (Fig. 1A) indicated that SBG leaf tissue may decline in quality more slowly than the other three species. However, a species × stage of maturity interaction for stem CP (Fig. 1B) suggested that stem CP declined more rapidly and to a lower level in SBG than in IWG and CWG.

A species × year interaction for leaf NDF (Fig. 2B) indicated that CWG and SBG differences in leaf NDF between years were greater than IWG and WWG. Higher precipitation in 1995 may have been more detrimental to CWG and SBG leaf quality. Foliar diseases can have an adverse affect on forage chemical composi-

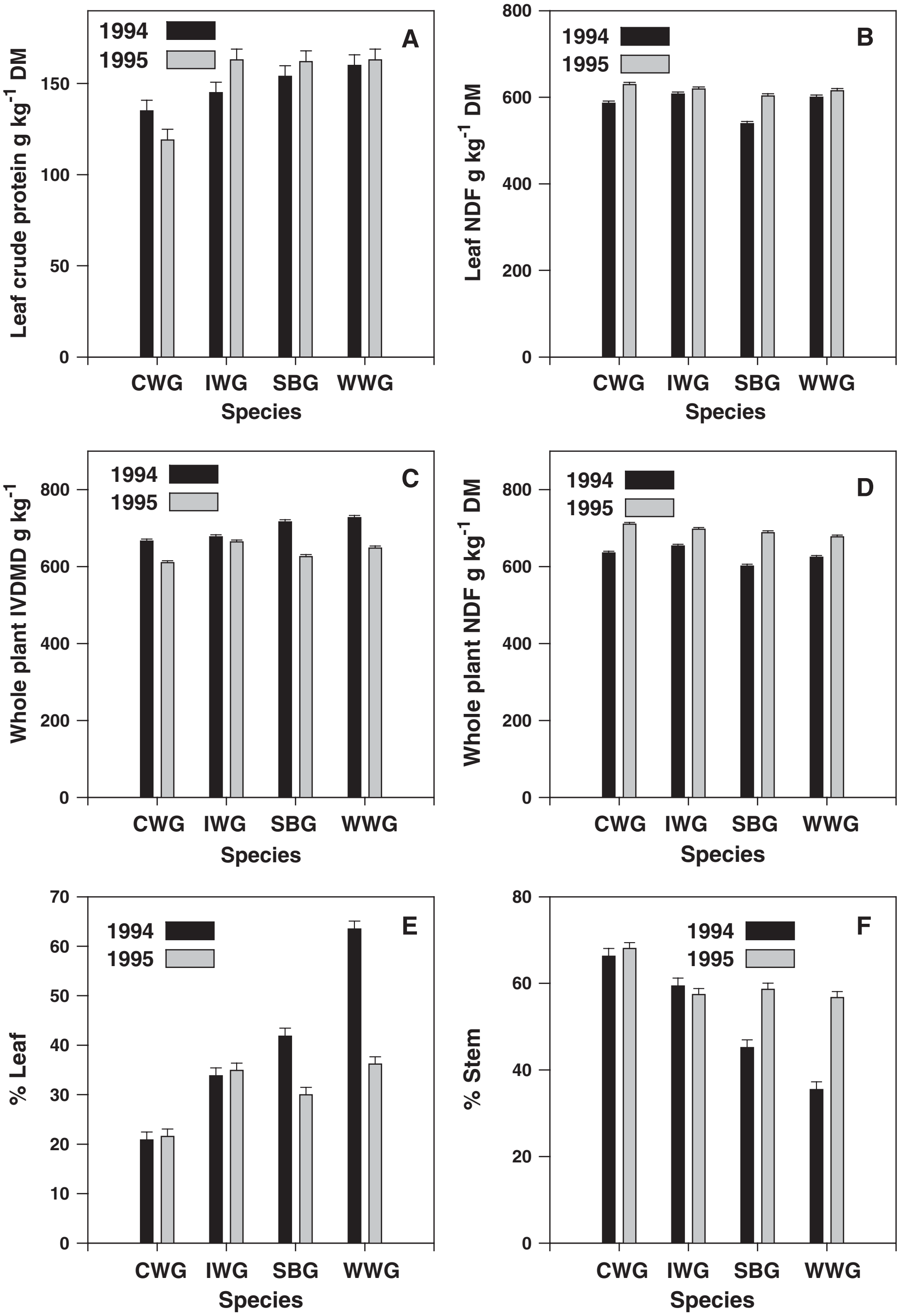

Fig. 2. Interaction effects of species and year for (A) leaf CP, (B) leaf NDF, (C) whole plant IVDMD, (D) whole plant NDF, (E) whole plant leaf percentage, and (F) whole plant stem percentage. Standard error bars on B, C, and D tend to blend with the graph bars.

tion (Karn and Krupinsky, 1983) especially during times of higher precipitation; however, the incidence of foliar diseases during the course of this study was low and they did not appear to affect any treatment responses.

Species × year interactions for whole plant IVDMD (Fig. 2C) and NDF (Fig. 2D) show that IVDMD was generally higher in 1994, while NDF was lower in 1994. These interactions resulted in part because IWG quality differed less between years than the other three species. Higher precipitation levels in 1995 likely resulted in more stem and less leaf tissue with the resulting dilution of whole plant quality. Species × year interactions for leaf and stem percentages support this thesis because IWG and CWG leaf and stem percentages differed little between years while leaf and stem percentages for SBG and WWG differed substantially between years.

In Saskatchewan, Canada, Lawrence and Warder (1979) assessed the nutritive quality of 20 grass populations and concluded that IWG was the best forage for hay production. Smooth bromegrass stems at a very

Table 6. Cultivar means for IVDMD, NDF, and CP for leaf, stem, and whole plant tissue. Means are averaged over stage of maturity and years.†

		Leaf			Stem			Whole plant		
Species	Cultivar	IVDMD	NDF	CP	IVDMD	NDF	CP	IVDMD	NDF	CP
		g kg^{-1}	—g kg^{-1} DM—		g kg^{-1}	—g kg^{-1} DM—		g kg^{-1}	—g kg^{-1} DM—	
CWG	Hycrest	754b	615a	119a	613a	687a	53b	641a	672a	–
CWG	Nordan	769a	600b	135a	606a	693a	63a	635a	673a	–
IWG	Manska	774a	622a	147a	627a	701a	64a	668a	683a	–
IWG	Reliant	778a	604b	162a	624a	689b	71a	673a	668b	–
SBG	Lincoln	800a	571a	165a	606a	693a	66a	677a	644a	–
SBG	Mandan 404	796a	571a	150a	592a	699a	56b	664b	646a	–
WWG	Rodan	766a	609a	160a	619b	676a	86a	674b	656a	–
WWG	Rosana	778a	606a	162a	652a	658b	85a	702a	645a	–
SE		5.9	6.2	7.7	6.0	4.8	4.2	5.1	5.0	–

† Means in the same column within the same species with different letters are significantly different ($P < 0.10$).

early stage of maturity have been reported to have a higher in vitro digestibility than leaves (Pritchard et al., 1963; Baron et al., 2000), but stem in vitro digestibility declined at a more rapid rate than leaves (Pritchard et al., 1963; Kilcher and Troelsen, 1973). A comparison of SBG, IWG, and CWG leaves and stems indicated that SBG leaves were highest in IVDMD, while SBG and CWG had comparable stem IVDMD (Wurster et al., 1971).

Cultivar

Comparison cultivars generally differed little in this study, but Reliant IWG had lower NDF in leaf, stem, and whole plant tissue (Table 6), as well as a higher leaf percentage (Table 8) compared to Manska. This suggests that Reliant may be a higher quality forage, even though neither cultivar was released because of superior nutritive quality. Although no previous nutritive quality or animal performance comparisons have been reported between Manska and Reliant, Moore et al. (1995) reported that Manska had superior dry matter yields, IVDMD and animal weight gains compared to Oahe and Slate IWG. Rosana WWG had higher IVDMD in stem and whole plant tissue than Rodan, but the two cultivars did not differ in leaf tissue quality. Rodan, the more recently released cultivar has been previously reported to have lower IVDMD than Rosana (Frank and Karn, 1988).

Nutritive quality comparisons between Nordan and other CWG cultivars is lacking in the literature. However, Wurster et al. (1971) reported that Nordan CWG had comparable digestibility and slightly lower CP than ‘P-27’ Siberian wheatgrass [*Agropyron sibericum* (Willd.) Beavu]. These two grasses were very similar in appearance and were referred to as crested because they appeared to be members of the same complex (Wurster et al., 1971). Smooth bromegrass was the most widely adapted and studied species used in this study; previous nutritive quality data for the cultivar Lincoln were reported by Pritchard et al. (1963). In the current study, Lincoln and the locally adapted Mandan 404 SBG differed little in quality, with Lincoln having slightly higher stem CP and whole plant IVDMD.

Stage of Maturity

Stage of maturity effects averaged over species, show that IVDMD in leaf, stem and whole plant tissues consistently declined with advances in maturity, but NDF in both stem and whole plant tissues showed a less consistent pattern of change as maturity increased.

Stage of maturity × year interactions for leaf IVDMD (Fig. 1C) and leaf NDF (Fig. 1D) show that leaf IVDMD was initially higher in 1995 than in 1994, but in 1995 it declined more rapidly and to a lower level by the anthesis + 10-d stage of maturity. Leaf NDF shows essentially the opposite, with leaf NDF lower in 1995 than 1994 at the vegetative stage followed by a rapid rise to a higher leaf NDF concentration at the latest stage of maturity. High precipitation levels in 1995 would have caused rapid leaf development and likely higher initial nutritive quality, but rapid growth was apparently accompanied by higher NDF concentrations, which reduced forage quality as the season progressed.

Research from Nebraska indicates that digestible dry matter yields of CWG were higher than SBG, IWG, and WWG in early May. However, at a mid-July sampling, CWG digestible dry matter yields had fallen sharply and were less than for SBG and IWG (Newell and Moline,

Table 7. Stage of maturity effects on IVDMD, NDF, and CP for leaf, stem and whole plant tissue. Means were averaged over species, cultivar, and year.†

	Leaf			Stem			Whole plant		
Stage of maturity	IVDMD	NDF	CP	IVDMD	NDF	CP	IVDMD	NDF	CP
	g kg^{-1}	—g kg^{-1} DM—		g kg^{-1}	—g kg^{-1} DM—		g kg^{-1}	—g kg^{-1} DM—	
Vegetative	863a	522d	184a						
Heading	801b	600c	158b	677a	689b	88a	732a	650c	–
Anthesis	747c	630b	138c	596b	697a	62b	649b	671a	–
Anthesis + 10-d	697d	647a	120d	579c	674c	54c	619c	660b	–
SE	3.6	3.1	3.3	3.2	2.5	1.7	2.8	2.5	–

† Means in the same column with different letters differ at $P < 0.05$.

Table 8. Percentage leaf, stem, and inflorescence tissue for cultivars and species averaged over stage of maturity and year.

		% Leaf		% Stem		% Inflorescence	
Species	Cultivar	Cultivar†	Species‡	Cultivar†	Species‡	Cultivar†	Species‡
CWG	Hycrest	23.5a	21.2c	66.1a	67.1a	10.4b	11.6a
CWG	Nordan	18.8b	–	68.2a	–	12.9a	–
IWG	Manska	31.8b	34.2b	59.5a	58.2b	8.7a	7.6b
IWG	Reliant	36.6a	–	56.9a	–	6.5b	–
SBG	Lincoln	38.2a	35.9b	51.9a	51.9c	9.8b	12.2a
SBG	Man. 404	33.6b	–	51.9a	–	14.6a	–
WWG	Rodan	46.8b	49.8a	48.8a	46.1d	4.8a	4.4c
WWG	Rosana	52.8a	–	43.4b	–	4.0a	–
SE		1.8	1.3	1.8	1.2	1.2	0.8

† Different letters indicate significant ($P < 0.10$) cultivar differences within species.
‡ Different letters indicate significant ($P < 0.05$) differences among species.

1978). Unfortunately, nutritive quality concentration data were not reported. Maturity effects on forage quality have been examined for CWG (Angell et al., 1990), and SBG (Pritchard et al., 1963; Sanderson and Wedin, 1989; Ferdinandez and Coulman, 2001). A comparison of the effects of maturity on these two grasses showed that at both heading and 2 wk after heading, SBG and CWG had similar levels of CP, with both having higher levels than IWG (Wurster et al., 1971). Lawrence and Warder (1979) reported that the decline in N in IWG and SBG did not differ over 7 wk, but during the same time period, organic matter digestibility of SBG was significantly lower than IWG at several maturities.

Tissue Percentage

Western wheatgrass in our study had the highest leaf tissue percentage with 57% at heading, 45% at the anthesis + 10-d stage, and an average of 50% over the three maturities. In other studies, SBG declined from 69% leaf tissue in early summer, to 41% 9 wk later and then remained at that level for another 5 wk (Kilcher and Troelsen, 1973). In the current study, SBG contained 44% leaf tissue at heading, but only 30% at anthesis +10-d, with an average over three maturities of 36%. At an early stage of maturity, Baron et al. (2000) reported that SBG had a leaf/stem ratio of 1.50, which declined to 0.35 at a late stage of maturity, and improved to 2.35 in regrowth forage. A leaf/stem ratio of 3.0 for CWG declined to 0.5 at full maturity (Ganskopp et al., 1997). We found that CWG had a low leaf percentage (26%) at heading, which declined to 18% at anthesis + 10-d. While leaf quality is important, it is also important to have a high leaf percentage and stems that maintain their quality.

Nutrient Quality Component Relationships

It is important to examine nutritive quality relationships to determine if any exist that could be exploited in either the analytical or breeding phase of forage research. From an analytical point of view, it would be advantageous to be able to predict IVDMD, for example, with a simpler chemical procedure. From the forage breeding point of view, it is important that forage digestibility, CP, and critical mineral levels are not compromised during the process of selection for enhanced agronomic characteristics. Significant relationships ($r = -0.56$–-0.83) between N or CP and NDF have been reported by several authors (Burns and Smith, 1980; Karn and Berdahl, 1984; Hoffman et al., 1993; Asay et al., 2001). Correlation coefficients between leaf CP and NDF in the present study ranged from $r = -0.44$** for SBG to $r = -0.80$** for CWG, with a correlation coefficient of $r = -0.63$** for all species. Negative relationships have also been reported between in vitro digestible organic matter (IVDOM) or IVDMD and NDF ranging from $r = -0.45$ in IWG (Berdahl et al., 1994) to $r = -0.72$ in Russian wildrye [(*Psathyrostachys juncea* (Fischer) Nevski] RWR (Asay et al., 2001).

Table 9. Correlation coefficients among IVDMD, NDF, and CP for leaf, stem, and whole plant tissue over all species, by species, and by stage of maturity.

	Leaf				Stem				Whole plant	
Variable	IVDMD vs. NDF	IVDMD vs. CP	NDF vs. CP	Obs. no.	IVDMD vs. NDF	IVDMD vs. CP	NDF vs. CP	Obs. no.	IVDMD vs. NDF	Obs. no.
					Overall species and by species					
All species	−0.85**	0.71**	−0.63**	256	−0.48**	0.63**	−0.14	192	−0.62**	192
CWG	−0.88**	0.80**	−0.80**	64	−0.54**	0.56**	−0.20	48	−0.58**	48
IWG	−0.83**	0.85**	−0.74**	64	−0.10	0.55**	0.19	48	−0.21	48
SBG	−0.81**	0.58**	−0.44**	64	−0.43**	0.71**	0.10	48	−0.68**	48
WWG	−0.86**	0.72**	−0.69**	64	−0.70**	0.67**	−0.15	48	−0.82**	48
					By stage of maturity					
Vegetative	−0.74**	−0.08	−0.20	64						
Heading	−0.55**	0.37**	−0.20	64	−0.76**	0.25*	−0.26*	64	−0.78**	64
Anthesis	−0.66**	0.50**	−0.42	64	−0.81**	0.37**	−0.39**	64	−0.80**	64
Anthesis + 10-d	−0.81**	0.42**	−0.36**	64	−0.75**	0.43**	−0.22	64	−0.75**	64

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Correlation coefficients between IVDMD and NDF in the current research for leaf tissue ranged from $r = -0.81^{**}$ for SBG to $r = -0.88^{**}$ for CWG. Positive relationships have been reported between IVDOM or IVDMD and CP or N (Lamb et al., 1984; Berdahl et al., 1994; Asay et al., 2001). Lamb et al. (1984) reported a low correlation coefficient between IVDMD and CP for first-cut CWG plants ($r = 0.24$), but a relatively high coefficient for second-cut plants ($r = 0.81$). Forage yield in CWG (Lamb et al., 1984) and leaf/stem ratio in IWG (Berdahl et al., 1994) did not have a close association with in vitro digestibility or CP concentration. Although relationships between nutritive quality components have not been as consistent as desired, in most cases it appears that breeding for increased digestibility should result in plants that also have higher CP and lower NDF.

CONCLUSIONS

There were significant differences in IVDMD, NDF, and CP among grass species, but species differences were not always consistent between leaf and stem tissue. Western wheatgrass had the highest whole plant IVDMD and lowest NDF, which was due to a high leaf percentage and good stem quality. Cultivar differences were less pronounced, but Reliant IWG and Rosana WWG appeared to have higher nutritive quality than their comparison cultivars. All species declined in IVDMD and increased in NDF as maturity advanced, but there were some species differences in the rate of change. Smooth bromegrass leaf tissue increased in NDF more slowly than the other species. There were important differences in leaf tissue percentage among species, which may be an important consideration in selecting species for high quality. Even though digestibility and CP declined in leaves as well as stems with advancing maturity, leaves always had higher quality. Nutritive quality relationships suggest that breeding for high IVDMD should result in increased CP and decreased NDF. With the exception of Rodan WWG, cultivars most recently released for forage production in the Northern Plains had nutritive quality comparable to older cultivars, even though in most cases quality traits were not included as selection criteria.

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